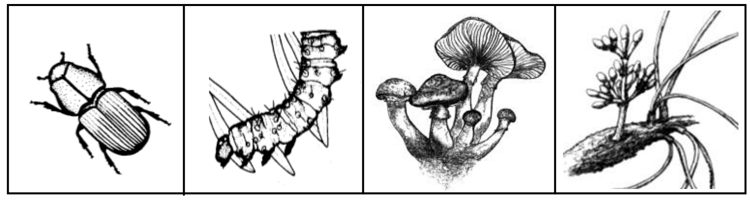
Forest Health Protection



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Current Status of Limber Pine in Montana

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Introduction

This report summarizes information about limber pine (*Pinus flexilis* James) found in published literature, unpublished reports, and data from survey plot records from a variety of sources. It describes current understanding of the population size, distribution, and condition of limber pine in Montana and provides suggestions to protect and restore this ecologically important species.

Background

Although marginal for timber values, limber pine is an important pioneer species that provides watershed protection and wildlife habitat in areas too harsh for other trees to survive (Steele 1990). Limber pine grows on dry sites at both upper and lower tree lines and in between on sites too harsh for other conifer species. Under warming climatic conditions, its drought tolerance is enhanced by its ability to photosynthesize in spring and fall, avoiding excessive water loss during hot, dry summers (Letts et al. 2009). On more moist sites conducive to limber pine and other conifers, limber pine often colonizes recently disturbed areas, but eventually becomes relegated to a minor stand component due to shade intolerance. Limber pine regeneration following large disturbance events is facilitated by the Clark's nutcracker (*Nucifraga columbiana* Wilson) (Coop and Schoettle 2009). Establishment is improved when nurse objects such as standing dead trees, fallen logs, or large rocks provide protection from excessive solar radiation, wind, soil movement, and other disturbances (Coop and Schoettle 2009). Once established, limber pine provides shade and other forms of protection for regeneration of other species such as Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and wax currant (*Ribes cereum* Dougl.) (Baumeister and Callaway 2006). Due to effective fire suppression, limber pine may have encroached into rangeland over the past century (Taylor and Schwandt 1998, Schuster et al. 1995), possibly impacting wildlife habitat. Bears, birds and rodents eat the large limber pine seeds and limber pine is sometimes the only tree providing cover and nesting habitat on dry, windy sites (Steele 1990). Chronic injury and mortality from the introduced disease white pine blister rust (WPBR) (caused by the fungus *Cronartium ribicola* Fisch.) in conjunction with occasional, sometimes widespread, mortality from mountain pine beetle (MPB) (*Dendroctonus ponderosae* Hopkins) has recently spurred heightened concern for the future of limber pine throughout its range (Kendall et al. 1996, Taylor and Gibson 1998, Lockman et al. 2004, Schoettle 2004).

Method

The studies cited in this report differ in sampling design and methodology. Because data

collection is inconsistent between studies, it is not appropriate to conduct summary analyses on combined data. However, we believe that compiling this information is the most effective way to assess the status of limber pine in Montana.

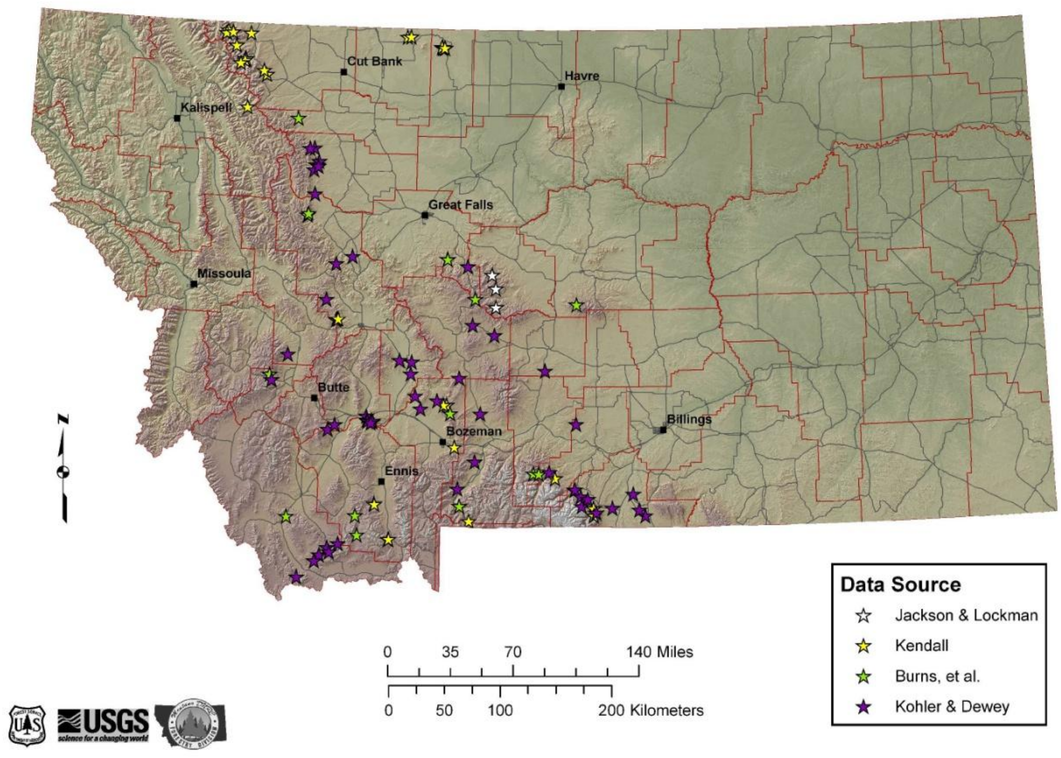
Plot Data Sources. Figure 1 and Appendix A describe and display data on limber pine status from 112 plots sampled during four separate studies. Data from 46 plots were retrieved from the whitebark-limber pine information system (WLIS) database (Lockman and DeNitto 2007) including 4 plots measured by Jackson and Lockman (2003) in 2002, but originally installed by Taylor and Sturdevant (1998) in 1996 and 42 plots installed by Katherine Kendall from 1995 through 1997 (Kendall 1997). Fifty plots were installed by the Montana Department of Natural Resources and Conservation (DNRC) from May through October in 2003 to evaluate whitebark (*Pinus albicaulis* Engelm.) and limber pine on Montana State lands (Kohler and Dewey 2005). Sixteen Forest Health Monitoring evaluation monitoring plots were installed as part of 83 long-term plots installed to assess and monitor the long-term ecological health of limber pine within white pine blister rust (WPBR) infested and threatened areas of the Rocky Mountains (Burns et al. In press). In addition to the four limber pine-specific surveys described above, limited Forest Inventory and Analysis (FIA) data were used. Since limber and whitebark pine are difficult to distinguish without mature cones, correct identification of these species is suspect in FIA plot data. FIA data were compiled in a spreadsheet by Ron Tymcio of the Rocky Mountain Research Station in Ogden, UT and included in WLIS.

Limitations of FIA Data. Data from the 234 FIA plots were combined with the 112 plots from the four limber pine-specific studies to produce Figure 2, but were not included in the WPBR infection map (Figure 3). A query of the FIA data showed only 18 of the 234 plots (7.7%) were coded for any WPBR infection. Limber pine-specific studies found much higher infection incidence ranging from 81% to 100% (see Results). We believe FIA underestimation is largely due to limits imposed on damage agent data collection specified in the FIA manual (Anonymous 2008). FIA protocol states "only trees with serious damage, insect, or pathogen activity are to be given damage codes other than 00 [no serious damage]." It continues:

> A general rule is to only code a damage category when something is affecting the tree that will cause one of the following:
>
> - Prevent it from living to maturity, or surviving 10 more years, if already mature.
> - Prevent it from producing marketable products. For example, code any damage preventing a timber species from having a minimum of one merchantable bolt.
> - Reduce (or has seriously reduced) the quality of the tree's products (e.g., potentially resulting from lightning strike, excessive lean, tree rot).

Given the great disparity in proportion of plots infected with WPBR between FIA data and the four limber pine-specific surveys, FIA data were not included in the WPBR distribution map (Figure 3).

Figure 1. Limber Pine Plot Distribution by Data Source

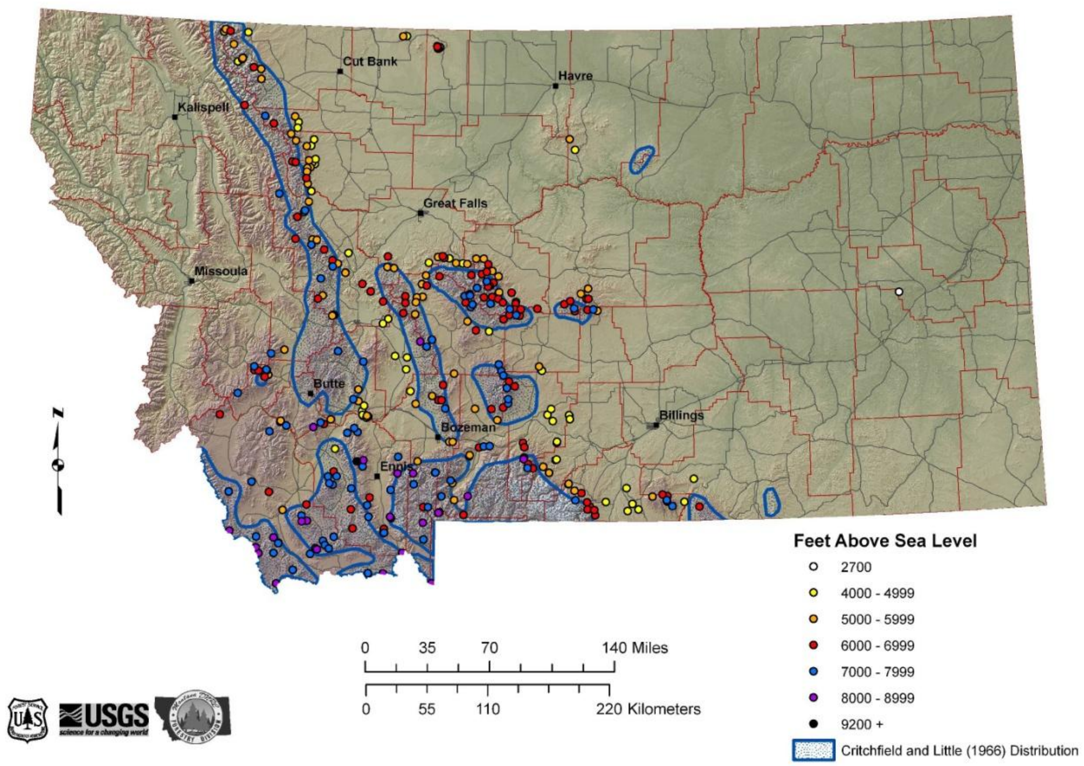


Results and Discussion

Population Distribution. Limber pine is found at elevations ranging from 2,700 feet near the community of Terry in far eastern Montana to around 9,000 feet in and around the Beaverhead-Deerlodge National Forest in southwestern Montana (Figure 2). Although several maps showing the distribution of limber pine in Montana have been published (Critchfield and Little 1966, Gibson et al. 2008, Taylor and Schwandt 1998, Steele 1990), the data we compiled expands previously documented limber pine range in several areas (Figure 2).

West of the Continental Divide, limber pine is largely confined to limited areas adjacent to the Divide, while scattered populations of limber pine can be found across much of eastern Montana. The only area historically documented as including limber pine, that was not identified through FIA or the limber pine-specific studies, is in the Little Rocky Mountains in north-central Montana. Much of the forest in the Little Rockies was lost to a large wildfire in 1936, greatly reducing the local limber pine population. Jackson and Cramer (2009) found only one limber pine in the Little Rockies on the Ft. Belknap Indian Reservation. This tree was outside limber pine's historical range (Critchfield and Little 1966).

Figure 2. Plot Elevation, Distribution, and Proximity to Historically Accepted Distribution of Limber Pine



Limber pine tends to occur on sites dominated by Douglas-fir, ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), and Rocky Mountain juniper (*Juniperus scopulorum* Sarg.) at lower elevations and lodgepole pine (*Pinus contorta* Dougl. ex Loud.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), and whitebark pine at higher elevations (Steele 1990). In addition, limber pine is found on areas that do not meet the FIA definition of forest land and where no FIA plots would be installed, such as lower treeline in Montana where the foothills of the Rocky Mountains meet the Great Plains. FIA sampling was conducted only on forest land that was at least 10 percent stocked by forest trees or 5 percent crown cover where stocking cannot be determined and the minimum area for classification of forest land is one acre and a crown width at least 120 feet wide (Anonymous 2008).

Limber Pine Coverage. We believe FIA provides the most accurate estimates of current limber pine coverage even though there may be some misidentification due to similarities with whitebark pine. Forest type classifications are based upon and named for the tree species forming a plurality of live trees when the stand is examined (Conner and O'Brien 1993). A query of the FIA database spanning inventory years 2003 – 2007 estimated 226,073 acres (range = 176,111 to 276,035 acres) of limber pine forest cover type in Montana (USDA Forest Service 2009). Although FIA inventories in 1989 estimated limber pine covered 145,541 acres (Conner and O'Brien 1993), we feel the more recent estimate does not represent an increase in coverage but rather is a more accurate estimate because it is based on more thorough inventories.

Cone Production. Cone production data were only available from two studies (Appendix B). Kohler and Dewey (2005) found an average of 53% of the trees with cones and Burns et al. (In

press) found an average of 30% of the trees over 4.5 feet tall with cones. Although it is unclear whether Kohler and Dewey (2005) recorded trees with green and brown (old) cones, Burns et al. (In press) only recorded green cones. This may explain the higher percentage of trees with cones reported by Kohler and Dewey. Large seed crops are believed to occur every two to four years (Krugman and Jenkinson 1974); however, we found no published information on variability in cone production between years for limber pine in Montana.

Regeneration. Limber pine regeneration was quantified on FIA plots and one limber pine-specific study (Burns et al. In press). These data are not comparable since FIA and Burns et al. (In press) used different definitions for seedlings. Based on 234 plots, FIA (inventory years 2003 through 2007) showed an average of 604 limber pine seedlings per acre in the limber pine forest type. Burns et al. (In press) found an average of 133 seedlings per acre in Montana. This is greater than the 95 seedlings per acre average found when Burns et al. (In press) combined data from Colorado, Wyoming and Montana. Although Kohler and Dewey (2005) recorded regeneration data on their plots, regeneration density could not be calculated due to their use of variably-sized plots.

Threats to Montana Limber Pine Populations. White pine blister rust is the greatest threat to Montana limber pine populations (Kendall et al. 1996, Taylor and Gibson 1998), persistently damaging and killing trees throughout much of its range across the state. Limber pine dwarf mistletoe (*Arceuthobium cyanocarpum* (A.Nelson ex Rydberg) Coulter & Nelson) is another chronic problem; however, it's only known to damage and cause mortality in south-central and southwestern Montana (Taylor and Mathiasen 1999). Periodically, mountain pine beetle kills large numbers of limber pine, particularly under severe drought conditions (Gibson et al. 2008). In the mid-1990's widespread Dothistroma needle disease (caused by *Dothistroma septosporum* (Doroguine) M. Morelet) (Taylor and Walla 1999, Taylor and Schwandt 1998, Jackson and Lockman 2003) damaged large numbers of limber pine in central and southern Montana, with many of the most heavily damaged trees dying within the following two to three years.

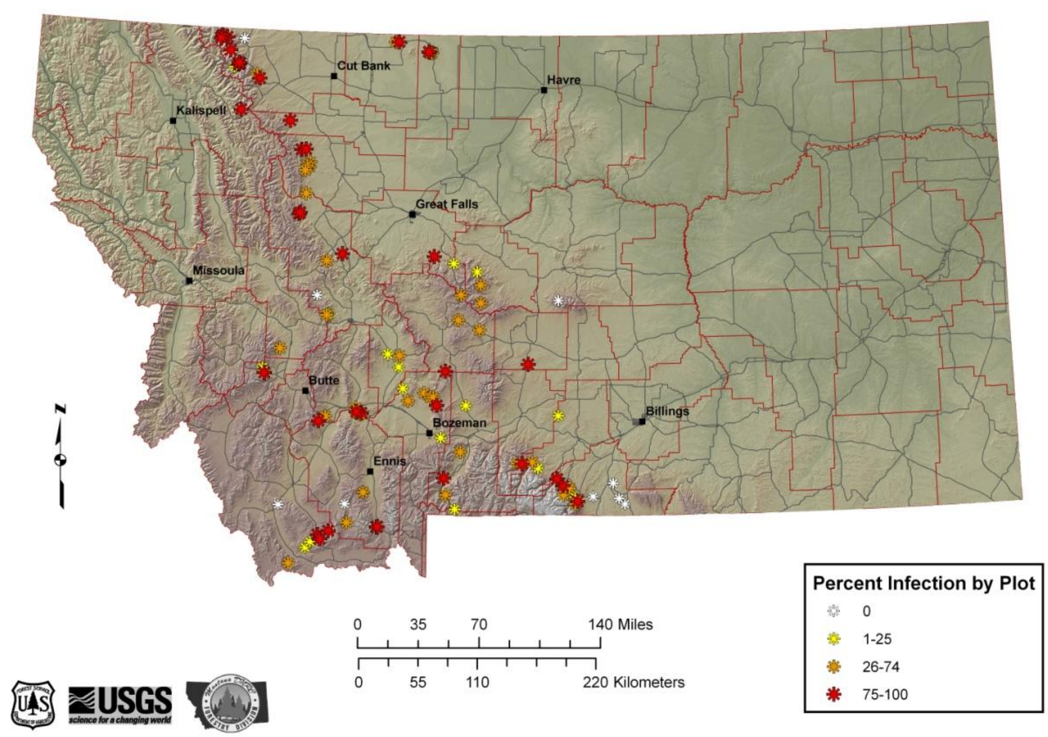
White Pine Blister Rust. Limber pine is highly susceptible to WPBR (Hoff et al. 1980). Fortunately, the species has some heritable resistance to the disease (Bingham 1972, Schoettle et al. 2009, Schoettle et al. In press). The fungus that causes WPBR first infected Montana limber pine in the mid- to late-1930's (Riley 1944) and has been present in much of limber pine's range in Montana for over half a century (Brown 1967). Yet, there are still sites where limber pine remain apparently free of the disease (Figure 3).

C. ribicola requires a five-needled pine and an alternate host in the genus *Ribes*, *Pedicularis*, or *Castilleja* to complete its complex life cycle and spread (McDonald et al. 2006). *C. ribicola* causes leaf spots on non-pine hosts and branch and stem cankers that often prove to be fatal on white pines. More than 80% of plots and 50% of individual limber pine trees examined in Montana were infected with WPBR (Appendix A). All Jackson and Lockman (2003), 95% of Kendall (1997), 90% of Kohler and Dewey (2005), and 81% of Burns et al. (In press) plots had at least one infected tree on them. Infection rates in Montana limber pine regeneration ranged from 10% (Burns et al. In press) to 28% (Kohler and Dewey 2005). Twelve percent of the limber pine regeneration in all 83 Burns et al. plots was infected with white pine blister rust; however, this may mean little since infected seedlings would be expected to die quickly and would be difficult to identify and document. It is not clear if the definition of regeneration differed among studies and could account for the difference in infection rates. Regeneration was taller in the Kohler and Dewey plots (mean height = 32 in.) than in the Burns et al. study, in which 45% of the regeneration was less than 10 inches tall. Taller trees would presumably be older and, therefore, exposed to WPBR spores for a longer time period, increasing the opportunity for infection.

Interest in modeling incidence and severity of white pine blister rust has increased in recent years. Although elevation, tree diameter, and summer precipitation appear to be important variables for modeling WPBR in limber pine, no reliable model is currently available due to the complex nature of WPBR epidemiology (Smith and Hoffman 2001, Kearns and Jacobi 2007). Howell et al. (2006) produced a WPBR risk map for Colorado based on historic weather data that can be overlaid on five-needled pines' ranges. The accuracy of their predictions will not be determined until the rust has spread for several more years. To complicate predictions further, "the characteristics of spread and intensification may change in the future due to genetic adaptations by *Cronartium ribicola*, an exponential increase in inoculum availability, changes in host distributions, or shifts in regional climate patterns" (Smith and Hoffman 2001).

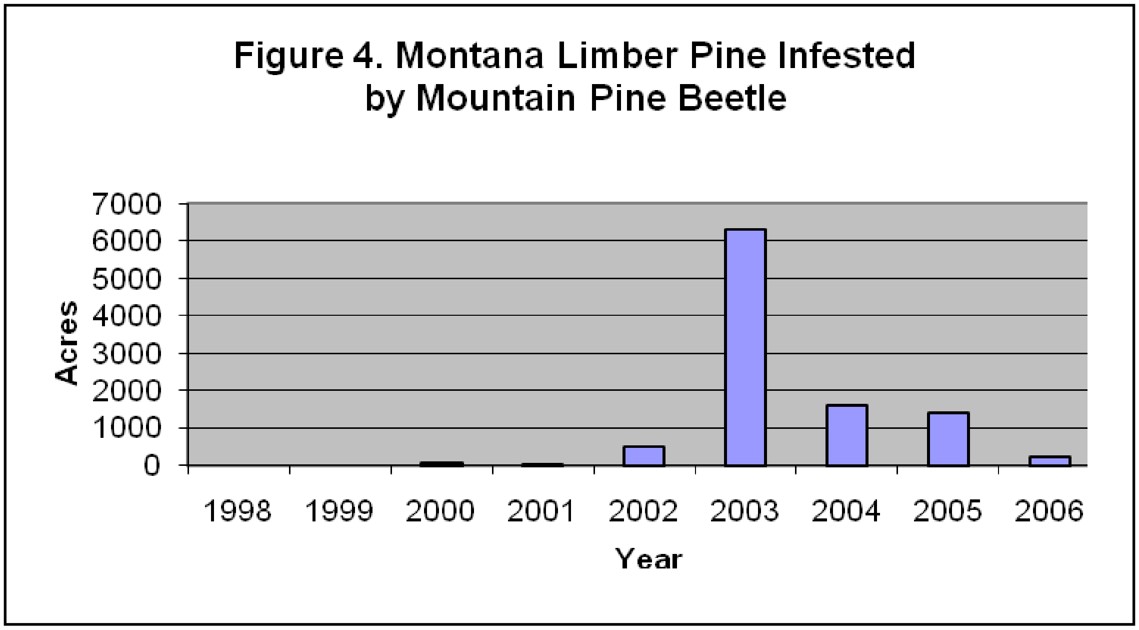
The native rust fungus *Cronartium comandrae* Peck causes a similar stem rust on lodgepole and ponderosa pine, but causes much less damage due to host genetic resistance. Discovery of a *C. ribicola* X *C. comandrae* hybrid in southwest Alberta limber pine has raised concerns about a potential change in host range, particularly for non-conifer alternate hosts (Joly et al. 2006). To date, there is no evidence that a host range change was created by the *C. ribicola* X *C. comandrae* hybrid.

Figure 3. White Pine Blister Rust Infection of Limber Pine by Plot



Mountain Pine Beetle. All native pines in Montana are susceptible to MPB and this insect occurs in most of limber pine's range in the state (Amman et al. 1985, Gibson et al. 2008). Limber pine can be a highly productive brood tree for MPB (Furniss and Carolin 1977, Cerezke 1995). Aerial detection surveys provide some information about limber pine mortality caused by mountain pine beetle, but these surveys underestimate acres affected. Aerial flights detect MPB mortality by mapping trees with red needles. Underestimates of mortality due to MPB occur because a dead tree's needles are red only the year it dies and only a small portion of

limber pine is surveyed in any given year. In particular, very little of the Rocky Mountain Front is surveyed because winds and terrain make flying difficult and demand for insect surveys of the area has historically been low (Sontag 2009). Even with this limited coverage, there was a noticeable increase in mortality in 2003 (Figure 4) which was also detected during field plot measurements (Gibson et al. 2008, Kohler and Dewey 2005).



Dothistroma Needle Disease. Dothistroma needle disease was first confirmed on Montana limber pine in 1997 (Taylor and Walla 1999, Taylor and Schwandt 1998). Although little is known about the biology and overall impact this disease may have on limber pine, above average summer precipitation in the early- and mid-1990's coincided with infection events and severe defoliation (greater than 90%). This was associated with increased mortality on monitoring plots established on the Lewis and Clark National Forest (Taylor and Schwandt 1998, Jackson and Lockman 2003, Taylor and Sturdevant 1998). Little damage has been reported in the last eight years.

Limber Pine Dwarf Mistletoe. In Montana, limber pine dwarf mistletoe is only found in the south-central and southwestern part of the state (Taylor and Mathiasen 1999). Where severe, limber pine dwarf mistletoe reduces height and diameter growth and seed production. This parasitic plant can cause tree mortality or reduce tree vigor, increasing susceptibility to other damaging agents. Dwarf mistletoes are naturally kept in check by stand-replacing fires. Most dwarf mistletoe management is done to reduce tree volume loss to the parasite. Since limber pine is a marginal timber species and dwarf mistletoes can provide some positive wildlife habitat and foraging opportunities, little management of limber pine dwarf mistletoe is undertaken in Montana.

Minor Pests. Twig beetle-caused dieback was observed on all sixteen Burns et al. plots in Montana, with more than 10% of the crown affected on one-fourth of the infested trees. Beetle species were not identified for that study. Although commonly associated with self-pruning, twig beetles can cause extensive damage and mortality in limber pine during drought and other stressful conditions.

Porcupine feeding was not observed on the sixteen forest health monitoring plots; however, it has been described as being locally light to

severe, causing partial and complete stem girdling, in low elevation limber pine of eastern Montana (Taylor and Gibson 1998) and western North Dakota (Potter and Green 1964).

Fire. Fuel loads on limber pines sites are usually light, allowing most large limber pines to survive wildfires (Steele 1990). Little is known about fire disturbance history of limber pine (Brown and Schoettle 2008); however, limber pine can recolonize a site opened by a stand-replacing wildfire (Coop and Schoettle 2009). Although rare, fire was shown to be the primary cause of local limber pine extinction in a study area on the Canadian Rocky Mountain Front Range (Webster and Johnson 2000).

Opportunities to Protect and Restore Montana Limber Pine

In light of recent concerns about impacts of future climate change on American forests, limber pine seems to be a species with great potential to protect watersheds and provide wildlife habitat in areas where other trees may be unable to grow. However, white pine blister rust has had, and will continue to have, a devastating effect on limber pine across much of the state. Although it is unlikely that limber pine will be eliminated by white pine blister rust, important ecological changes are likely to occur. Significant changes are expected in forest distribution, reforestation after fire or other disturbance, forest succession rate and outcome, and wildlife habitat (Schoettle 2004).

As with other threatened white pines, facilitating an increase in genetic resistance across the limber pine population is an essential component to restoring severely impacted areas and reducing future impacts of WPBR in areas not yet affected by the disease (Schoettle and Sniezko 2007, Schwandt 2006). Strategies to enhance limber pine fitness include: introducing resistant stock through artificial regeneration; managing forest composition to favor limber pine; diversifying age class structure towards more islands of young cohorts which encourages natural selection for rust resistance among a landscape of mature limber pine that mitigate short-term impacts across the landscape; and, increasing host vigor to reduce losses of resistant germplasm from mountain pine beetle and other agents (Schoettle and Sniezko 2007).

Schoettle and Sniezko (2007) identify options to proactively manage high elevation white pines threatened by WPBR. Some of these management options can also be used to facilitate restoration of areas already impacted by the disease. Accelerating the spread of naturally occurring resistance to this invasive pathogen while protecting potentially resistant trees from mountain pine beetle, other insects and diseases, and fire, is critical to restoring impacted ecosystems and returning resilience to these ecosystems. Seed collection from United States Rocky Mountain limber pine populations has been initiated to support white pine blister rust screening, genetic conservation, restoration projects, and research to support restoration projects (Schoettle 2009, Schoettle et al. 2007). Montana seed was collected from three locations in 2009: state land near Anaconda, the Lewis and Clark National Forest near Kings Hill pass, and the Ruby River Valley of the Beaverhead-Deerlodge National Forest. Seeds were collected from the Logging Creek area of the Lewis and Clark National Forest in 2010 (Dopler 2010). These sites were selected due to accessibility and known cone crops. Efforts should be made to better identify plus trees and expand seed collections to include a greater portion of the Montana population.

Rust resistance screening of progeny from limber pine trees in Montana will begin in 2011 and will help identify if similar resistance mechanisms identified in the Southern Rocky Mountain limber pine populations are present in the Montana populations (Schoettle, personal communication). Studies of outplanting techniques have been undertaken to the north in Alberta (Smith et al. In press) and to the south in Colorado and Wyoming (Casper et al, In press). These studies will likely help guide successful outplanting techniques for Montana.

Bureau of Land Management in Wyoming has recently developed silvicultural prescriptions for

managing low elevation limber pine on their lands in the presence of white pine blister rust (Means 2010). These may have application to low elevation limber pine in Montana.

To better understand the current and projected status of limber pine in Montana, additional monitoring plots should be installed and monitored on a five year cycle. In addition, ecologically significant areas should be identified for restoration. However, additional research is needed to develop methods for restoring limber pine ecosystems (Schoettle and Sniezko 2007, Langor 2007).

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References

Amman, G.D., McGregor, M.D., and Dolph, R.E. 1985. Mountain pine beetle. USDA For. Serv. For. Insect and Disease Leaflet 2. Washington, DC. 12 pp.

Anonymous. 2008. Interior West Forest Inventory & Analysis Field Procedures (V3.02). Rocky Mountain Res. Sta., USDA For. Serv. 422 p.

Baumeister, D. and Callaway, R. 2006. Facilitation by *Pinus flexilis* during succession: a hierarchy of mechanisms benefits other plant species. Ecology 87(7): 1816-1830.

Bingham, R.T. 1972. Taxonomy, crossability, and relative blister rust resistance of 5-needled pines. In: Biology of rust resistance in forest trees. USDA For. Serv. Misc. Pub. Vol 1221, pp 271 – 278.

Brown, D.H. 1967. White pine blister rust survey in Montana and Wyoming 1966. Div. of State and Private Forestry, USDA For. Serv. Missoula, MT. 11 p.

Brown, P.M. and Schoettle, A.W. 2008. Fire and stand history in two limber pine (*Pinus flexilis*) and Rocky Mountain bristlecone pine (*Pinus aristata*) stands in Colorado. International Journal of Wildland Fire 17:339-347.

Burns, K.S., Blodgett, J., Jackson, M.B., Howell, B., Jacobi, W., Schoettle, A., Casper, A.M., Klutsch, J. *In press*. Monitoring Limber Pine Health in the Rocky Mountains and North Dakota (INT-EM-06-03). Chapter 18 in K.M. Potter and B.L.Conkling, eds., Forest Health Monitoring 2009 National Technical Report. General Technical Report SRS-xxx. Asheville, North Carolina: U.S. Department of Agriculture, Forest Service, Southern Research Station.

Casper, A.M., Jacobi, W.R., Schoettle, A.W., Burns, K.S. *In press*. Restoration Planting Options for Limber Pines in the Southern Rocky Mountains. In: Proceedings of the High-Five Symposium; June 28-30, 2010, Missoula, MT, Proceedings RMRS-P-xx. Fort Collins, CO: USDA For. Serv., Rocky Mountain Research Station. Pp. xx-xx.

Cerezke, H.F. 1995. Egg gallery, brood production, and adult characteristics of mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytidae), in three pine hosts. The Canadian Entomologist 127:955-965.

Connor, R.C. and O'Brien, R.A. 1993. Montana's Forest Resources. Res. Bull. INT-81. Intermountain Res. Sta., USDA For. Serv. Ogden, UT. 96 p.

Coop, J.D. and Schoettle, A.W. 2009. Regeneration of Rocky Mountain bristlecone pine (*Pinus aristata*) and limber pine (*Pinus

flexilis) three decades after stand-replacing fires. For. Ecol. and Man. 257: 893-903.

Critchfield, W.B. and Little, E.L. 1966. Geographic Distribution of the Pines of the World. Misc. Pub. 991. USDA For. Serv., Washington, DC. 97 p.

Dopler, R. 2010. E-mail communication (9/13/2010). Culturist. Helena/Lewis and Clark National Forests. USDA For. Serv. Helena, MT.

Furniss, R.L. and Carolin, V.M. 1977. Western Forest Insects. Pacific Northwest. Forest and Range Experiment Station, USDA For. Serv. Misc. Pub. No. 1339. p.353.

Gibson, K., Skov, K., Kegley, S., Jorgensen, C., Smith, S., and Witcosky, J. 2008. Mountain Pine Beetle Impacts in High-Elevation Five-Needle Pines: Current Trends and Challenges. Forest Health Protection, State & Private Forestry, USDA For. Serv. Missoula, MT. 32 p.

Hoff, R., Bingham, R.T., and McDonald, G.I. 1980. Relative blister rust resistance in white pines. Eur. J. For. Path. 10:307-316.

Howell B, Burns K, Kearns H. 2006. Biological Evaluation of a Model for Predicting Presence of White Pine Blister Rust in Colorado Based on Climatic Variables and Susceptible White Pine Species Distribution USDA For. Serv., Rocky Mountain Region, Renewable Resources. Biol. Eval. R2-06-04. 15 p.

Jackson, M. and Cramer, W. 2009. Ft. Belknap Limber Pine. MFO-TR-09-33. Forest Health Protection, USDA For. Serv. Missoula, MT. 4p.

Jackson, M. and Lockman, B. 2003. Update on limber pine decline and mortality on the Lewis and Clark National Forest, Montana. Forest Health Protection Report 03-4. Forest Health Protection, USDA For. Serv. Missoula, MT. 8 p.

Joly, D.L., Langor, D.W., and Hamelin, R.C. 2006. Molecular and morphological evidence for interspecific hybridization between Cronartium ribicola and C. comandrae on Pinus flexilis in southwestern Alberta. Plant Dis. 90:1552.

Kearns, H. and Jacobi, W. 2007. The distribution and incidence of white pine blister rust in central and southeastern Wyoming and northern Colorado. Can. J. For. Res. 37:1-11.

Kendall, K.C. 1997. Internal plot data. Northern Rocky Mountain Science Center, USGS, Glacier National Park, West Glacier, MT.

Kendall, K., Ayers, D., and Schirokauer, D. 1996. Limber Pine Status from Alberta to Wyoming. Page 23 in R.E. Keane, editor, USDA For. Serv., Intermountain Research Station, Nutcracker Notes 7.

Kohler, S. and Dewey, J. 2005. An assessment of factors affecting whitebark and limber pine health on State of Montana lands – 2003. Unpublished report. Division of Forestry, Montana Department of Natural Resources and Conservation. Missoula, MT. 23 p.

Krugman, S.L. and Jenkinson, J.L. 1974. Pinus L. Pine. *In* Seeds of Woody Plants in the United States. Tech. Coord. C.S. Schopmeyer. Agricultural Handbook No. 450. USDA Forest Service, Washington, D.C. 883 p.

Langor, D.W. 2007. Status of limber pine (*Pinus flexilis*) in Alberta. Alberta Wildlife Status Report No. 62. Alberta Sustainable Resource Development and Alberta Conservation Association, Edmonton, AB. 17 p.

Letts, M.G., Nakonechny, K.N., Van Gaalen, K.E., and Smith, C.M. 2009. Physiological acclimation of Pinus flexilis to drought stress on contrasting slope aspects in Waterton Lakes National Park, Alberta, Canada. Can. J. For. Res. 39:629-641.

Lockman, I.B. and DeNitto, G.A. 2007. WLIS: The whitebark-limber pine information system and what it can do for you. In Proceeding of the Conference Whitebark pine: a Pacific Coast perspective. Goheen, E.M. and Sniezko, R.A. Tech. Coords. Ashland, OR. p. 146.

Lockman, B., Hoffman, J., Jackson, M., and Gibson, K. 2004. Insect and disease status of limber pine. Pages 7,9. Nutcracker Notes. WPEF, Missoula, MT. Issue 7.

McDonald, G.I., Richardson, B.A., Zambino, P.J., Klopfenstein, N.B., and Kim, M.S. 2006. Pedicularis and Castilleja are natural hosts of Cronartium ribicola in North America: a first report. Forest Pathology 36:73-82.

Means, R. 2010. Whitebark and Limber Pine (Five Needle Pine) Management Guidelines for Wyoming BLM. Internal Report Wyoming Bureau of Land Management, Cheyenne Wyo. 10p.

Potter, L.D. and Green, D.L. 1964. Ecology of a northeastern outlying stand of *Pinus flexilis*. Ecology. 45:866-868.

Riley, M.C. 1944. Blister rust control, Glacier National Park, 1944. *In* White Pine Blister Rust Control in the Northwestern Region, January 1 to December 31, 1944. Division of Plant Disease Control, USDA Bureau of Entomology and Plant Quarantine. Spokane, Washington. Pg. 87.

Schoettle, A.W. 2004. Ecological roles of five-needle pines in Colorado: potential consequences of their loss. In: Sniezko, R.A., Samman, S., Schlarbaum, S.E., and Kriebel, H.B., eds. Breeding and genetic resources of five-needle pines; growth, adaptability and pest resistance; 2001 July 23-27; Medford, OR, USA. IUFRO Working Party 2.02.15. Proceedings RMRS-P-32. Fort Collins, CO: USDA For. Serv., Rocky Mountain Research Station. pp. 124-135.

Schoettle, A.W. 2009. Proposal for gene conservation collections of Rocky Mountain populations of *Pinus flexilis* and *Pinus aristata* in 2009. Proposal submitted to the Forest Health Protection Gene Conservation Program.

Schoettle, A.W. and Sniezko, R.A. 2007. Proactive intervention to sustain high-elevation pine ecosystems threatened by white pine blister rust. J. For. Res. 12:327-336.

Schoettle, A.W., Sniezko, R.A., Burns, K.S., and Freeman, F. 2007. Preparing the landscape for invasion – Early intervention approaches for threatened high elevation white pine ecosystems. *In:* Goheen, EM; RA Sniezko, techn. coords. Proceedings of the conference Whitebark Pine: a Pacific Coast Perspective. 2006 Aug 27-31, Ashland OR. R6-NR-FHP-2007-01. Portland, OR: Pacific Northwest Region, Forest Service, US Department of Agriculture; pp 72-75. Available on-line at: http://www.fs.fed.us/r6/nr/fid/wbpine/proc.shtml

Schoettle, A.W., Sniezko, R.A., and Burns, K.S. 2009. Sustaining *Pinus flexilis* ecosystems of the Southern Rocky Mountains (USA) in the presence of *Cronartium ribicola* and *Dendroctonus ponderosae* in a changing climate. In: Breeding and Genetic Resources of Five-Needle Pines Conference, IUFRO Working Party 2.02.15, Yangyang, Republic of Korea, 2008 September 22–26. Ed. By Noshad, D.; Noh, E.; King, J.; Sniezko, R. Yangyang: Korea Forest Research Institute. Pp. 63-65. http://www.iufro.org/download/file/4989/1191/20215-yangyang08-proceedings.pdf/

Schoettle, A.W., Sniezko, R.A., Kegley, A., and Burns, K.S. *In press*. Preliminary Overview of the First Extensive Rust Resistance Screening Tests of *Pinus flexilis* and *Pinus aristata.* In: Proceedings of the High-Five Symposium; June 28-30, 2010, Missoula, MT, Proceedings RMRS-P-xx. Fort Collins, CO: USDA For. Serv., Rocky Mountain Research Station. Pp. xx-xx.

Schuster, W.F, Mitton, J.B., Yamaguchi, D.K., and Woodhouse, C.A. 1995. A comparison of limber pine (*Pinus flexilis*) ages at lower and upper treeline sites east of the continental divide in Colorado. A. Midl. Nat. 133:101-111.

Schwandt, J.W. 2006. Whitebark pine in peril: a case for restoration. USDA For. Serv. Forest Health Protection Report R1-06-28. Coeur d'Alene, ID. 20 pp.

Smith, C., Poll, G., Gillies, C., Praymak, C., Miranda, E. and Hill, J. *In press*. Limber Pine Seed and Seedling Planting Experiment in Waterton Lakes National Park, Canada. In: Proceedings of the High-Five Symposium; June 28-30, 2010, Missoula, MT, Proceedings RMRS-P-xx. Fort Collins, CO: USDA For. Serv., Rocky Mountain Research Station. Pp. xx-xx.

Smith, J.P. and Hoffman, J.T. 2001. Site and stand characteristics related to white pine blister rust in high-elevation forests of southern Idaho and western Wyoming. Western North American Naturalist 61(4) 409-416.

Sontag, S.M. 2009. Personal communication. Aerial Survey Technician. Forest Health Protection, USDA For. Serv. Missoula, MT.

Steele, R.S. 1990. Pinus flexilis James, Limber pine. In: Silvics of North America. Volume 1. Conifers. Burns, R.M. and Honkala, B.H. eds. USDA For. Serv. Ag. Hndbk 654. Washington, D.C. 675 p.

Taylor, J.E., and Gibson, K.E. 1998. Service visit, limber pine in eastern Montana. Unpublished Trip Report. Forest Health Protection, State & Private Forestry, USDA For. Serv. Missoula, MT. 4 p.

Taylor, J.E., and Mathiasen, R.L. 1999. Limber pine dwarf mistletoe. Forest Insect & Disease Leaflet 171. USDA For. Serv., Washington, D.C. 8 p.

Taylor, J.E., and Schwandt, J.W. 1998. Dothistroma needle blight of limber pine in Montana. Forest Health Protection Report 98-4. State & Private Forestry, USDA For. Serv. Missoula, MT. 7 p.

Taylor, J., and Sturdevant, N. 1998. Limber pine mortality on the Lewis and Clark National Forest, Montana. Forest Health Protection Report 98-5. State & Private Forestry, USDA For. Serv. Missoula, MT. 7 p.

Taylor, J.E., and Walla, J.A. 1999. First report of *Dothistroma septospora* on native limber and whitebark pine in Montana. Plant Dis. 83:590.

USDA Forest Service. 2009. Forest Inventory Data Online (FIDO). http://fiatools.fs.fed.us/fido/index.html. Accessed on February 20, 2009.

Webster, K.L. and E.A. Johnson. 2000. The importance of regional dynamics in local populations of limber pine (*Pinus flexilis*). Ecoscience 7:175-182.

Appendix A. Limber pine study managers and percent of trees infected with white pine blister rust per plot. Data from plot numbers beginning with WLIS were extracted from the whitebark-limber pine information system database.

Plot #	Study Manager(s)	% Inf.	Plot #	Study Manager(s)	% Inf.	Plot #		% Inf.
DNRC1	Kohler & Dewey	76	DNRC59	Kohler & Dewey	52	WLIS 22	Kendall	46
DNRC2	Kohler & Dewey	74	DNRC60	Kohler & Dewey	0	WLIS 23	Kendall	35
DNRC3	Kohler & Dewey	96	DNRC61	Kohler & Dewey	0	WLIS 24	Kendall	7
DNRC4	Kohler & Dewey	34	DNRC62	Kohler & Dewey	0	WLIS 25	Kendall	7
DNRC5	Kohler & Dewey	56	DNRC63	Kohler & Dewey	0	WLIS 26	Kendall	2
DNRC6	Kohler & Dewey	20	DNRC64	Kohler & Dewey	16	WLIS 27	Kendall	25
DNRC7	Kohler & Dewey	4	DNRC65	Kohler & Dewey	96	WLIS 28	Kendall	23
DNRC8	Kohler & Dewey	96	DNRC66	Kohler & Dewey	66	WLIS 29	Kendall	56
DNRC9	Kohler & Dewey	88	DNRC67	Kohler & Dewey	50	WLIS 30	Kendall	2
DNRC10	Kohler & Dewey	72	DNRC68	Kohler & Dewey	96	WLIS 31	Kendall	100
DNRC11	Kohler & Dewey	72	DNRC69	Kohler & Dewey	80	WLIS 32	Kendall	100
DNRC12	Kohler & Dewey	62	DNRC70	Kohler & Dewey	72	WLIS 33	Kendall	86
DNRC13	Kohler & Dewey	70	MT1	Burns et al.	77	WLIS 34	Kendall	100
DNRC14	Kohler & Dewey	64	MT2	Burns et al.	84	WLIS 36	Kendall	100
DNRC15	Kohler & Dewey	24	MT3	Burns et al.	15	WLIS 37	Kendall	92
DNRC16	Kohler & Dewey	14	MT4	Burns et al.	79	WLIS 38	Kendall	58
DNRC17	Kohler & Dewey	30	MT5	Burns et al.	51	WLIS 39	Kendall	23
DNRC18	Kohler & Dewey	78	MT6	Burns et al.	91	WLIS 40	Kendall	100
DNRC19	Kohler & Dewey	88	MT7	Burns et al.	35	WLIS 41	Kendall	100
DNRC20	Kohler & Dewey	90	MT8	Burns et al.	75	WLIS 42	Kendall	93
DNRC21	Kohler & Dewey	64	MT9	Burns et al.	83	WLIS 43	Kendall	0
DNRC22	Kohler & Dewey	78	MT10	Burns et al.	53	WLIS 44	Kendall	39
DNRC23	Kohler & Dewey	0	MT11	Burns et al.	74	WLIS 45	Kendall	0
DNRC24	Kohler & Dewey	16	MT12	Burns et al.	0	WLIS 46	Kendall	46
DNRC25	Kohler & Dewey	20	MT13	Burns et al.	54	WLIS 47	Kendall	80
DNRC26	Kohler & Dewey	30	MT14	Burns et al.	0	WLIS 48	Kendall	100
DNRC27	Kohler & Dewey	6	MT15	Burns et al.	0	WLIS 49	Kendall	100
DNRC28	Kohler & Dewey	58	MT16	Burns et al.	9	WLIS 50	Kendall	100
DNRC29	Kohler & Dewey	97	WLIS 4	Jackson&Lockman	19	WLIS 51	Kendall	100
DNRC30	Kohler & Dewey	48	WLIS 8	Jackson&Lockman	54	WLIS 52	Kendall	82
DNRC31	Kohler & Dewey	78	WLIS 12	Jackson&Lockman	84	WLIS 53	Kendall	64
DNRC32	Kohler & Dewey	44	WLIS 16	Jackson&Lockman	57	WLIS 54	Kendall	63
DNRC33	Kohler & Dewey	64	WLIS 17	Kendall	43	WLIS 55	Kendall	61
DNRC34	Kohler & Dewey	64	WLIS 18	Kendall	8	WLIS 56	Kendall	89
DNRC35	Kohler & Dewey	92	WLIS 19	Kendall	16	WLIS 57	Kendall	37
DNRC56	Kohler & Dewey	64	WLIS 20	Kendall	14	WLIS 58	Kendall	66
DNRC57	Kohler & Dewey	90	WLIS 21	Kendall	14	WLIS 59	Kendall	82
DNRC58	Kohler & Dewey	80						

Appendix B. Summary of limber pine cone production by plot (% of live limber pine over 4.5 feet tall with cones).

Plot #	Study Mnager(s)	Percent of Trees	Plot #	Study Manager(s)	Percent of Trees
DNRC1	Kohler & Dewey	76	DNRC34	Kohler & Dewey	67
DNRC2	Kohler & Dewey	48	DNRC35	Kohler & Dewey	91
DNRC3	Kohler & Dewey	56	DNRC56	Kohler & Dewey	60
DNRC4	Kohler & Dewey	40	DNRC57	Kohler & Dewey	36
DNRC5	Kohler & Dewey	53	DNRC58	Kohler & Dewey	22
DNRC6	Kohler & Dewey	66	DNRC59	Kohler & Dewey	0
DNRC7	Kohler & Dewey	76	DNRC60	Kohler & Dewey	71
DNRC8	Kohler & Dewey	88	DNRC61	Kohler & Dewey	100
DNRC9	Kohler & Dewey	62	DNRC62	Kohler & Dewey	82
DNRC10	Kohler & Dewey	69	DNRC63	Kohler & Dewey	86
DNRC11	Kohler & Dewey	52	DNRC64	Kohler & Dewey	57
DNRC12	Kohler & Dewey	80	DNRC65	Kohler & Dewey	27
DNRC13	Kohler & Dewey	78	DNRC66	Kohler & Dewey	9
DNRC14	Kohler & Dewey	53	DNRC67	Kohler & Dewey	9
DNRC15	Kohler & Dewey	36	DNRC68	Kohler & Dewey	72
DNRC16	Kohler & Dewey	20	DNRC69	Kohler & Dewey	55
DNRC17	Kohler & Dewey	60	DNRC70	Kohler & Dewey	57
DNRC18	Kohler & Dewey	14	MT1	Burns et al.	14
DNRC19	Kohler & Dewey	52	MT2	Burns et al.	27
DNRC20	Kohler & Dewey	9	MT3	Burns et al.	35
DNRC21	Kohler & Dewey	39	MT4	Burns et al.	39
DNRC22	Kohler & Dewey	51	MT5	Burns et al.	27
DNRC23	Kohler & Dewey	15	MT6	Burns et al.	12
DNRC24	Kohler & Dewey	77	MT7	Burns et al.	61
DNRC25	Kohler & Dewey	86	MT8	Burns et al.	40
DNRC26	Kohler & Dewey	57	MT9	Burns et al.	9
DNRC27	Kohler & Dewey	22	MT10	Burns et al.	19
DNRC28	Kohler & Dewey	63	MT11	Burns et al.	63
DNRC29	Kohler & Dewey	37	MT12	Burns et al.	13
DNRC30	Kohler & Dewey	23	MT13	Burns et al.	31
DNRC31	Kohler & Dewey	47	MT14	Burns et al.	62
DNRC32	Kohler & Dewey	62	MT15	Burns et al.	19
DNRC33	Kohler & Dewey	75	MT16	Burns et al.	11